Some features of the Early Cretaceous sedimentation in the Cis-Caucasia reflected in magnetic properties of the sedimentary cover

Andrew Y. GUZHIKOV & Edward A. MOLOSTOVSKY
Institute of Geology, Saratov State University,
Moskovskaya street, 161, Saratov 410750 (Russia)
guzhikovay@info.sgu.ru

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ABSTRACT
This paper present the results from petromagnetic studies of the North Caucasus-Lower Cretaceous deposits. Analyses of the magnetic properties of rocks in base sections have allowed to reveal several impulses of tectonic activation in the Hauterivian and Barremian. The impulses were accompanied by transport of magnetic terrigenous material from the magnetic complexes of the Central Ridge into the Cis-Caucasian Basin.

KEY WORDS
Petromagnetism,
scalar magnetic characteristics,
magnetic susceptibility,
Para-Tethys,
Early Cretaceous.

RÉSUMÉ
Quelques caractéristiques de la sédimentation du Crétacé inférieur en Cis-Caucasie à travers les propriétés pétromagnétiques de la couverture sédimentaire.
Cet article présente les résultats d'une étude pétromagnétique sur les dépôts du Crétacé inférieur du Nord Caucase. Les analyses des propriétés magnétiques des roches ont montré plusieurs poussées de l'activité tectonique durant l'Hauterivien et le Barrémien. Ces impulsions se sont accompagnées d'un transport du matériel terrigène depuis les complexes magnétiques de la ride centrale jusque dans le bassin Cis-Ouralien.

MOTS CLÉS
Pétromagnétisme,
caractéristiques magnétiques,
susceptibilité magnétique,
Para-Téthys,
Crétacé inférieur.

INTRODUCTION

The results of petromagnetic research on the Lower Cretaceous deposits from the central and eastern parts of the North Caucasus are presented with the geologic interprerations. Six reference sections from Dagestan, Chechnya, Kabarda and the Mineral Water District were examined (Fig. 1). They contain carbonate and terrigenous facies of the marine Lower Cretaceous (Berriasian to Albian).

The geologic history of the region is considered in voluminous literature, with the early stage of its development being analysed both from the positions of classical fixism, and on the basis of more recent mobilistic ideas.

The fixist conception states that the Caucasus was developing according to the classic geosyncline scheme, with the principal structural elements inherited from the end of the Palaeozoic-beginning of the Mesozoic (Shevchenko & Rezanov 1978; Sholpo 1978). The mobilistic models present the geodynamic evolution of the Caucasian region as resulting from continental plates crushing and moving apart, and the Benioff zones rifting and subsequently migrating southwards (Khain 1975; Adamiya *et al.* 1982).

The analyses of the lithofacies spatial divisions and thickness of the Lower Cretaceous rocks, have revealed the principal structures forming the frame of the North Caucasian Region (Sholpo 1978): (1) the elevated southern margin of the Scythian Plate, conjugated with the transversal Stavropol high; (2) an intensive submergence zone, spatially concurrent with the Terek-Caspian piedmont trough; (3) the elevation of the Great Caucasus (Fig. 1).

The nature of these structures is interpreted in different ways. Some authors regard the zone of the Great Caucasus as an inherited horst-anticlinorium Mesozoic (Shevchenko & Rezanov 1978; Sholpo 1978), others – as an island arc (Khain 1975; Adamiya *et al.* 1982). The Terek-Caspian trough is accordingly interpreted as a geosyncline axial zone or a marginal island-arc basin.

For our reconstructions, it is important to note, that irrespective of palaeotectonic interpretations, two geomorphologically distinct sourcelands, the northern and the southern ones exist in the Early Cretaceous, with an intermediate zone of intensive submergence; this latter one acting as an area of active marine sedimentation in the Early Cretaceous. The Mesozoic palaeogeography of the North Caucasus is generally being analysed at the level of major sedimentation-tectonic cycles, frequently uniting several geologic periods and epochs (Khain 1968; Dorduev 1989). Konyukhov & Olenin (1955) and Konyukhov (1961) recognised an independent Lower Cretaceous Stage in the geologic development of the eastern Cis-Caucasia; this is peculiar for a prolonged transgression, that has started in the Berriasian and continued through the Late Albian. Carbonate-terrigenous sedimentation prevailed during the early stage of the Lower Cretaceous transgression (Berriasian-Valanginian). Terrigenous deposits are characteristic of the Barremian, Aptian and Albian.

The determination of the terrigenous inflow sources to the Cis-Caucasian Basin presents one of the debatable problems for the Mesozoic palaeogeography of the North Caucasus. This problem is discussed in detail in a number of important papers on the lithology of the Mesozoic sedimentary complexes from the region, but the authors have different conclusions. Konyukhov (1961) considered the Northern Land to have been the principal distributive province during the whole of the Lower Cretaceous. Grossgeim (1961) cited the elevations of the Great Caucasus as the main distributive province. Expanding Grossgeim's scheme (1961), Sholpo (1978) supposes, that in the Callovian, the Caucasus has undergone active erosion, that has practically stopped in the Neocomian, resumed in the late Barremian and reached its maximum in the Aptian and Albian.

In this paper, the authors got some additional palaeogeographic information while analysing the data on scalar magnetic characteristics of the Lower Cretaceous beds from the North Caucasus. The petromagnetic data let us to carry out the detailed analyses of sedimentation in the Early Cretaceous, to specify the importance of the northern and southern distributive provinces and to evaluate the changes of the palaeogeochemical conditions in the course of transgression development.

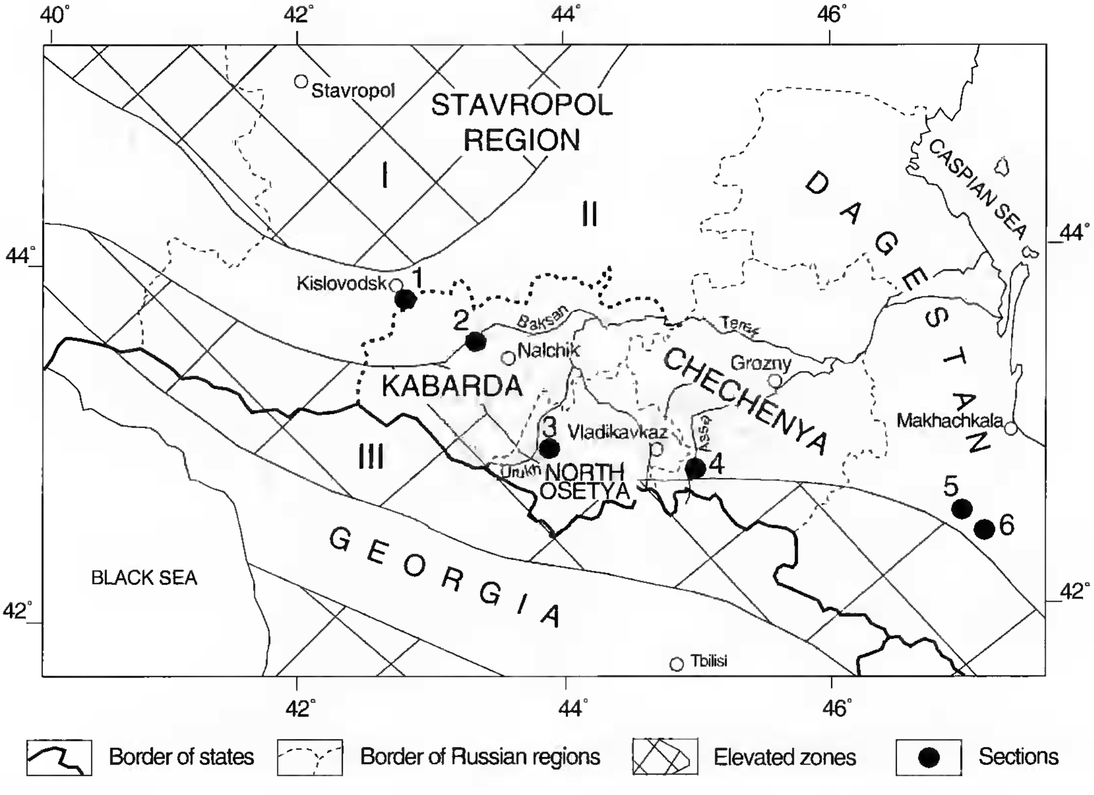

FIG. 1. — Location map. Sections: **1**, Kislovodsk city; **2**, the Baksan River; **3**, the Urukh River; **4**, the Assa River; **5**, Gergebil Village; **6**, Akusha Village. **I**, the southern margin of the Scythian Plate (Stavropol High); **II**, the Terek-Caspian piedmont trough; **III**, elevation of the Great Caucasus.

RESULTS

Magnetic measurements of the rocks from 1500 stratigraphic levels were performed in six Lower Cretaceous reference sections (Fig. 1). Petromagnetic sampling from two sections (Kislovodsk and Gergebil) was duplicated in the adjacent outcrops of the same age. Various facies were examined: limestones, marls, sandstones, aleurolites and clays. A significant spectrum of magnetic features was analysed in the course of laboratory experiments: magnetic susceptibility (k), natural remanent magnetisation (Jn), remanent saturation magnetisation (Jrs), destructive field of remanent saturation magnetisation (H'cs), and magnetic susceptibility measured upon heating the rocks up to 500° in air medium (k_t). The variations in the $dk = k_t - k$ parameter reflect the concentration changes of initially nonmagnetic iron sulphides. Pyrite and marcasite change into magnetite upon heating, which results in increasing magnetic susceptibility. Thus, dk increase reflects the contents of newly generated magnetite, and consequently, the concentrations of original FeS_2.

The data summarised have shown many magnetic characteristics to render generally similar information. To avoid the unnecessary duplication, only the k and dk parameters are used in the present paper.

Optical methods and thermodifferential analyses have demonstrated detrital magnetite to be the principal magnetic medium in the bulk of samples. Its presence is diagnosed in thermomagnetic curves from disappearance of remanent magnetisation around 580 °C (magnetite Curie point) (Fig. 2A-C). Magnetic saturations of the samples have revealed the magnetically mild

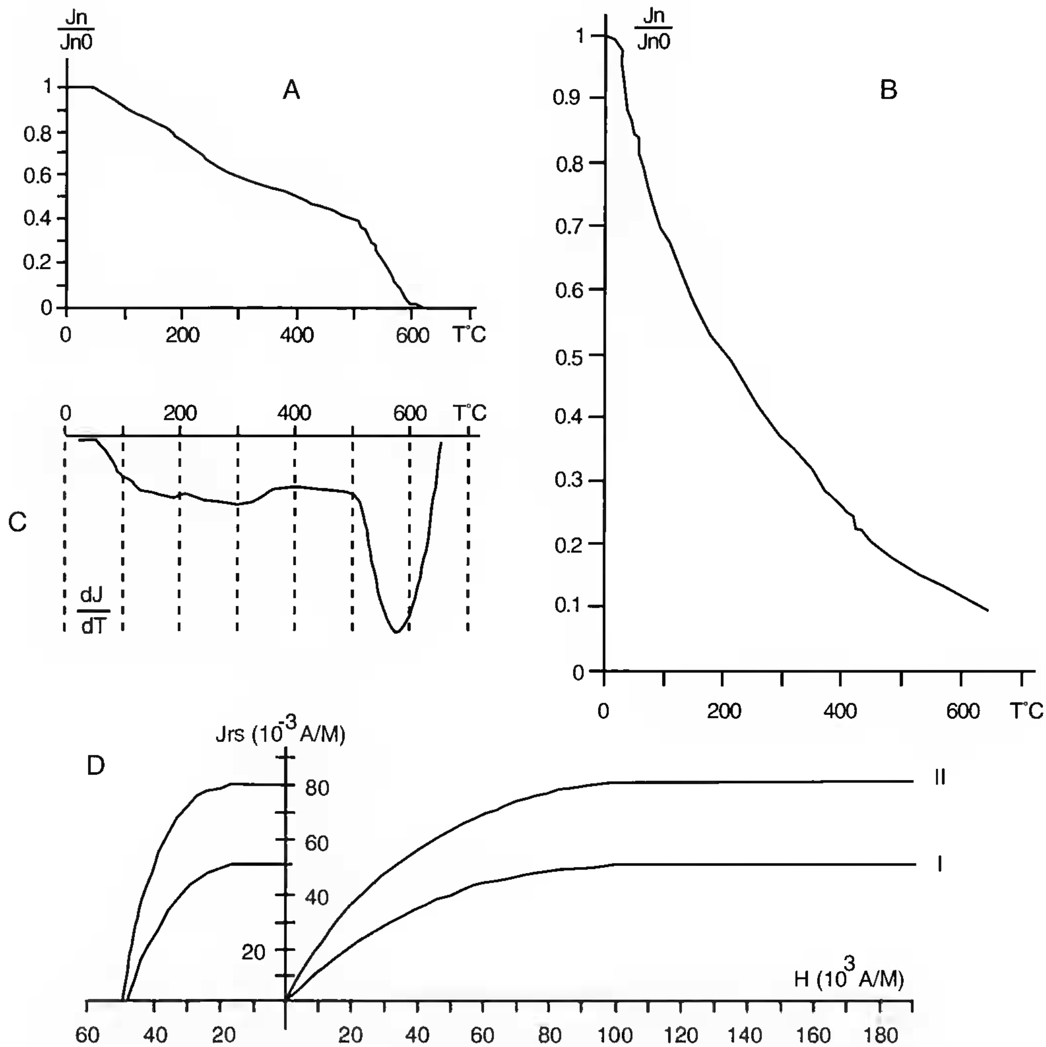

FIG. 2. — Results of magneto-mineralogic analyses for the Lower Cretaceous deposits from the North Caucasus. Thermodemagnetisation curves: **A**, clay (Aptian, Gergebil Village); **B**, limestone (Hauterivian, Gergebil Village); **C**, differential thermomagnetic analysis curve for aleurolite (Hauterivian, the Baksan River); **D**, magnetic saturation and demagnetisation curves: **I**, for aleurolite (Berriasian, the Assa River); **II**, for sandstone (Barremian, Akusha Village).

phase Hs = 32-64 A/m, H'cs = 24-50 magnetite (Fig. 2D). The data of immersional analyses testify to allothigenic nature of magnetite. The coarsest Fe_3O_4 grains are angular and possess clear traces of transportation by water: scratches and hatching on the sides and edges.

Grossgeim's data (1961) confirm the conclusion, that magnetic features of the Lower Cretaceous beds from the Cis-Caucasia were controlled mainly by detrital magnetism.

Carbonate beds are peculiar for extremely low magnetism. Terrigenous complex is characterised by considerable variations in magnetic susceptibilities. Their levels are practically independent on rock lithologies or structural-textural features, but are generally determined by the spatial-structural positions of the sections and by the stratigraphic positions of the sequences.

According to its petromagnetic properties, the Lower Cretaceous terrigenous complex from the

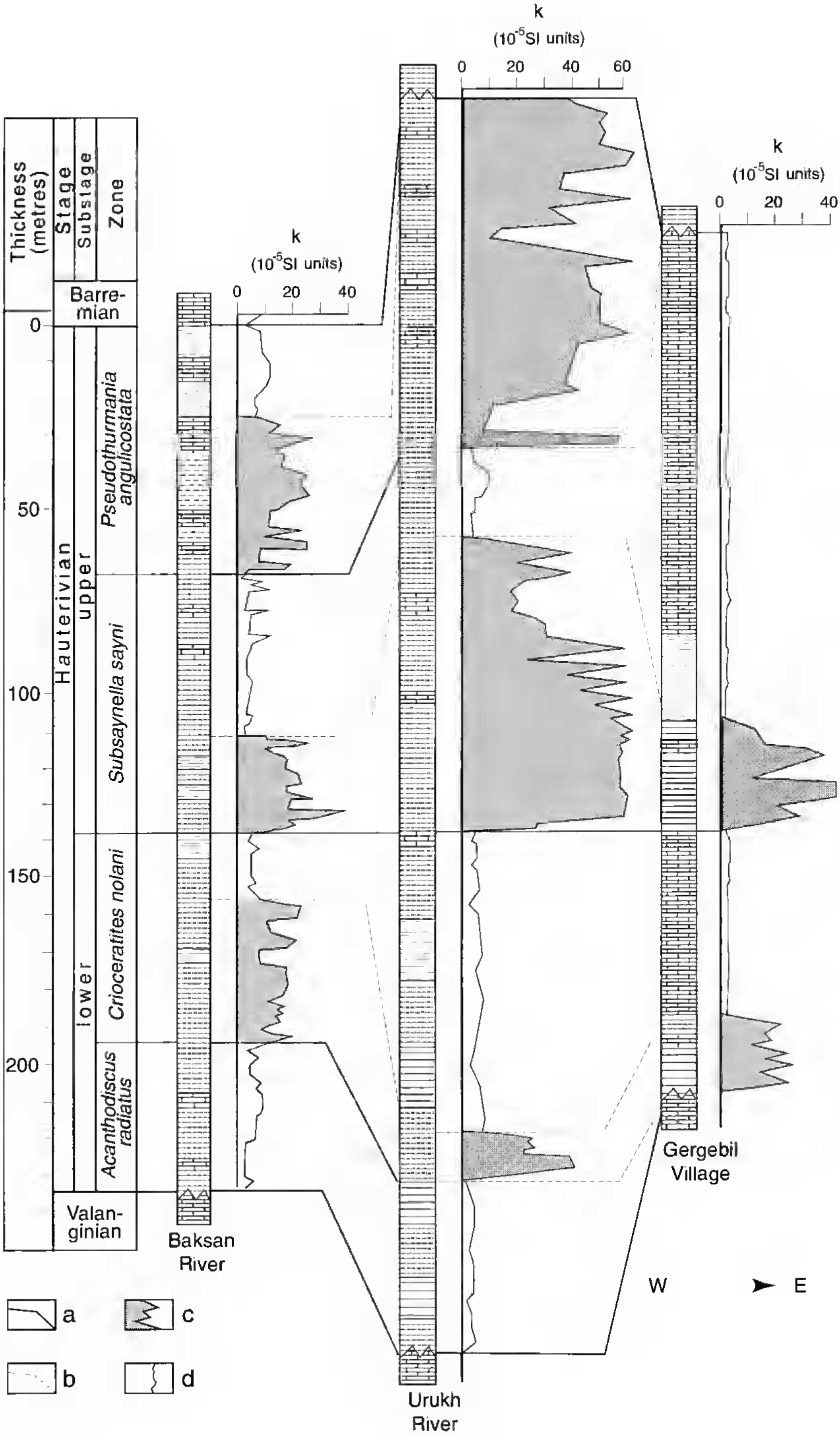

FIG. 3. — Palaeontologic and petromagnetic correlations of the Hauterivian deposits from the North Caucasus. a, correlation lines according to palaeontological data; **b**, *idem* according to petromagnetic data; **c**, petromagnetic intervals highly magnetic; **d**, *idem* low magnetic. For legend of lithology and gap, see Appendix 1.

North Caucasus may be divided into two distinct parts (Appendixes 1-6) in all the sections, except the Kislovodsk one (Appendix 1). The Hauterivian-Barremian beds stand out against the general background due to higher magnetism and great dispersion of magnetic values. Alternating groups of highly and low magnetic layers are recognised within the sections, with the thickness of 10 to 100 m and the magnitudes of Jn and k varying between $1\text{-}65.10^{-5}$ SI units and $0.2\text{-}3.10^{-3}$ A/m, respectively.

A certain sequence may be outlined in distribution of the petromagnetic intervals over the stratigraphic section; the highly magnetic intervals correspond to the lower parts of biozones or substages, and the low magnetic ones-to the upper parts. Thus, all the Hauterivian biozones (except the *Acanthodiscus radiatus* one) and Barremian substages correspond to binomial petromagnetic rhythms (PR), with the boundaries defined from sharp (by the factors of two, three or more) differences in Jn and k values (Appendixes 1-6).

The number of rhythms and the thickness are not constant and depend on the section completeness and sedimentation rates in various structural-facies zones. On the basis of all the considered data, at least three petromagnetic rhythms are recognised in the Hauterivian (Fig. 3). All of them occupy some definite stratigraphic positions and may be used for detailed section divisions and correlations, evaluation of washouts and sedimentation gaps (Fig. 3).

Another peculiarity of the Hauterivian-Barremian sedimentation consists in distinct structural-spatial differentiation of the sediments according to their magnetic properties.

The littoral-marine sandstones from the Hauterivian Stage of the Mineral Water Region, are characterised by low and uniform magnetism ($k = 0\text{-}3.10^{-5}$ SI units). The Hauterivian bed magnetism increases up to $10\text{-}20.10^{-5}$ SI units to the south-east, in the Baksan Section. The values reach their maxima in the Urukh River Basin, where most of the samples having k varying between $15\text{-}50.10^{-5}$ SI units over the whole of the Hauterivian and Barremian sections. In south-eastern Dagestan, the highly magnetic horizons are separated and localised in fairly narrow intervals of the section (Fig. 4).

The Cis-Caucasian Aptian and Albian beds form an independent lithological-magnetic complex, sharply different from the Hauterivian-Barremian one by its low magnerism (Fig. 4). In the Aptian deposits, the k values vary within $1\text{-}12.10^{-5}$ SI units without any significant differentiation over the section.

The Albian deposits are even lower magnetic ($k = 1\text{-}10.10^{-5}$ SI units). Nevertheless, in Dagestan sections, four binomial petromagnetic rhythms may be outlined from variations in magnetic susceptibility. In the reference section of the Albian near the Akusha Village, the first thythm (K 1) covers the lower and the middle substages, the K 2 – the *Dipoloceras cristatum-Hysteroceras varicosum* zones, the K 3 – the *Mortoniceras inflatum* zone, and the K 4 – the *Stoliczkaia dispar* zone (appendix 6). In the lower rhythm, the boundary between the low and moderately magnetic intervals coincides with the *O. royssianum*/*A. intermedius* biozone boundary.

A peculiar feature of the Aptian-Albian petromagnetic complex consists in a sharp increase of the rock magnetic susceptibilities in certain stratigraphic intervals, upon heating up to 500°.

The Lower Aptian and lowermost Middle Aptian (the *Epicheloniceras subnodosocostatum* zone) beds do not reveal any significant increase in magnetic susceptibility (Fig. 4).

An anomalous burst of dk values (up to 450.10^{-5} SI units) is associated in all the sections with the boundary between the Middle Aptian zones *E. subnodosocostatum* and *Parahoplites melchioris* (Fig. 4).

The thermokappametric diagrams for the deposits from the *P. melchioris* zone, Upper Aptian and Albian, have individual peculiarities in each of the sections (Fig. 4).

In the vicinity of Kislovodsk, high dk values (up to 400.10^{-5} SI units) are recorded only in the lower part of the *P. melchioris* zone.

In the basin of the Urukh, high values of magnetic susceptibility are characteristic both, of the Upper Aptian and of the Albian complexes ($dk = 150\text{-}450.10^{-5}$ SI units and $dk = 100\text{-}400.10^{-5}$ SI units, respectively).

In Dagestan, anormal dk values are characteristic of the uppermost Aptian and of the Albian. However, in the section near Gergebil, the

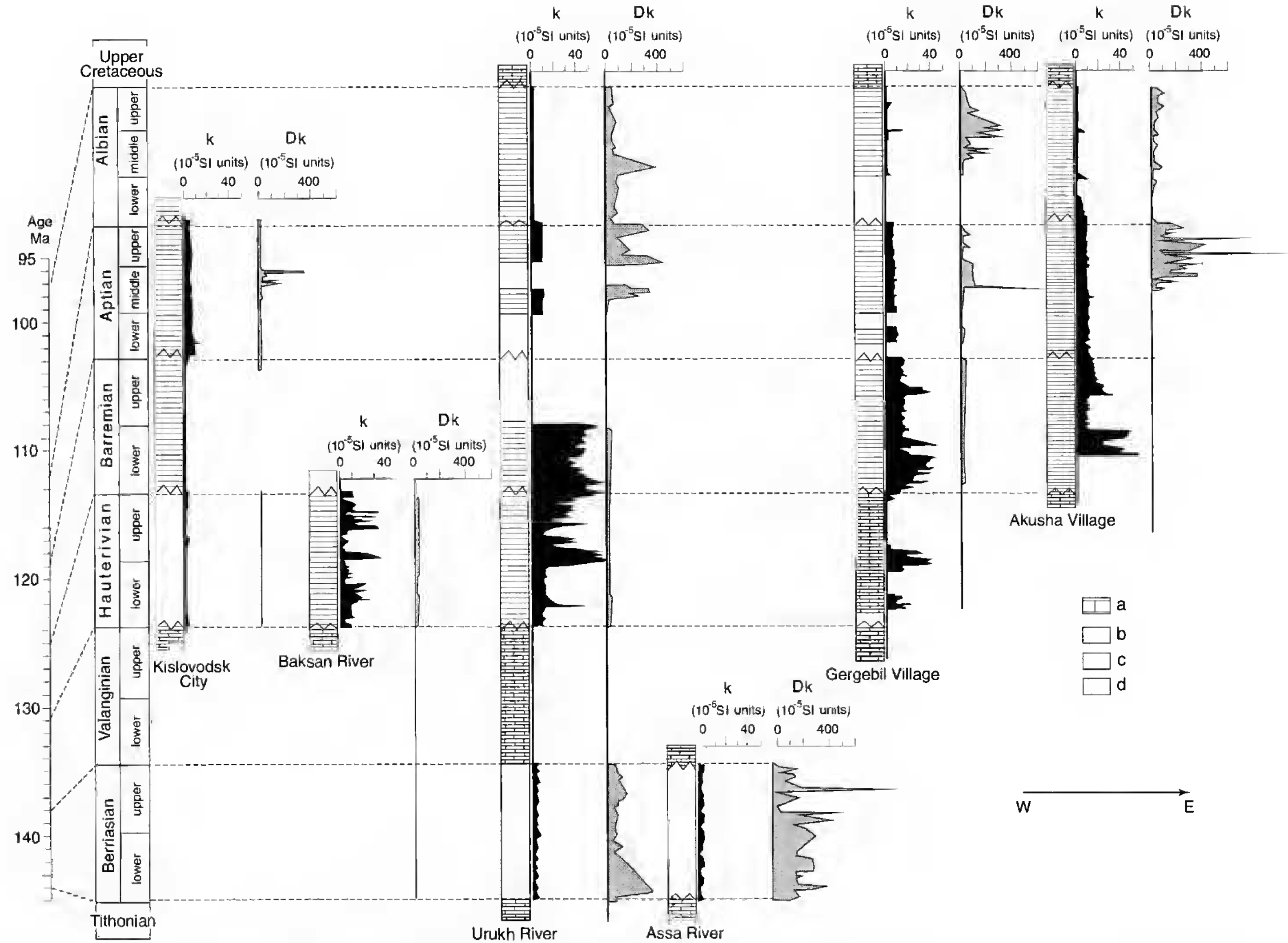

FIG. 4. — Petromagnetic characteristics of the Lower Cretaceous deposits from the North Caucasus (Age Ma from Harland *et al.* 1982). **a**, chiefly carbonate beds; **b**, chiefly terrigenous beds; **c**, carbonate-terrigenous beds; **d**, absence of deposits.

Albian is marked with higher dk values (to 300.10^{-5} SI units), than the upper Aptian, while the reverse is observed near Akusha.

Variations in magnetic susceptibility increase are associated with the palaeontological boundaries. Thus, in the Albian Section from Akusha, the smoothed dk curve (the dk curve was smoothed by means of calculating the sliding arithmetic mean from five samples, at a step of one sample, Appendix 6) demonstrated distinct rhythms, while three of its intervals with the dk > dkav stratigraphically coincide with the zones *Pseudosonneratia eodentata-Oxytropidoceras roys-sianum*, *H. orbignyi-H. varicosum* and *Stoliczkaia dispar*, respectively.

As seen in Figure 4, the values of k and dk parameters reveal clear inverse relationship: the highly magnetic Hauterivian-Barremian parts of the sections are characterized by minimal increases of magnetic susceptibility; on the contrary, the highest dk values are recorded in the low magnetic Aptian-Albian sequences.

PALAEOGEOGRAPHIC INTERPRETATION OF THE DATA

Rock magnetic properties are primarily determined by the compositions and concentrations of allothigenic or/and authigenic ferromagnetic minerals; these vary depending on sedimentation settings. From this follow the previously formulated postulates for the geologic interpretation of petromagnetic data (Molostovsky 1986; Guzhikov & Molostovsky 1995).

The following theses are relevant to the present theme:

1. The magnetisation intensity of sedimentary rocks, containing allothigenic ferromagnetics, is determined by the palaeogeographic and tectonic factors, controlling baring, drifting and precipitation of terrigenous materials. Petromagnetic differentiation of the layers in a stratigraphic section reflects deposition rhythms and changing sedimentation settings, resulting from geodynamic reconstructions in baring areas, and, mostly, from the sourceland changes.

2. Variations in the dk parameter adequately reflect changing geochemical settings and hydrogen-sulphide contamination of the bottom silts or its absence.

Complex analyses of the magnetic properties, and of the materials on lithofacies stratigraphic distributions on fossil biocoenoses, textural-structural features of the rocks, allow to obtain a fairly complete idea of the evolution of sedimentation settings in the Cis-Caucasian Basin during the Early Cretaceous.

All the data combined, provide the grounds for recognising the independent Lower Cretaceous step in the geologic development of the North Caucasian Region, comprising several major stages, each one from 10.5 to 27.5 million years long.

The first stage, equivalent to the Berriasian and Valanginian, coincides with the beginning of a major transgression, marked by chiefly carbonate sedimentation. Deposition took place in the settings of a relatively shallow and well-oxygenated warm basin (Konyukhov & Olenin 1955; Konyukhov 1961; Khain 1968). The limited terrigenous input and extremely low magnetism of the rocks testify to the lowland terrain in probable sourcelands, and low magnetism of the source rocks.

The Hauterivian has opened a new stage in the Early Cretaceous sedimentation cycle. The consistent sea transgression northwards, coincided with tectonic activation of the Great Caucasus and elevation of the southern margin of the Scythian Plate.

The increased magnetism of the Hauterivian-Barremian part of the section, indicates, that the principal sourceland did not lie in the Northern Land with the low magnetic sedimentary cover being washed out, but was situated in the Great Caucasus territory, characterised by wide development of the Upper Palaeozoic and Jurassic intrusions and of the dike complex of basites (Afanasyev 1968).

Judging from the characters of petromagnetic sections, the territory of the Central Caucasus was the principal magnetic material supplier to the Lower Cretaceous basin. The bulk of the magnetic terrigenous input was accumulated within the Osetin syncline, in the basins of the Baksan and Urukh. The eastern part of the Great

Caucasus was less important in this respect. The Western Caucasus, with its granitoid intrusions of Malkinskaya group, did not exert any obvious influence on the sedimentation in the Cis-Caucasian Basin. The southern part of the Scythian Plate and the adjacent Stavropol projection (Fig. 1) served as the main distributive provinces for the western part of the Central Cis-Caucasia. This is indicated by low and uniform magnetisation of the Hauterivian arkoses from the Mineral Water District (Fig. 4), practically devoid of ferromagnetic materials.

The petromagnetic differentiation of the sediments over the stratigraphic section, being adequate to sedimentation rhythms, testifies to pulsatory character of deposition and occasional changes of sourcelands. Chronologic coincidences of the petromagnetic rhythms and biozones are indicative of the event nature of magnetic and palaeontologic boundaries, and of their paragenetic dependence on the regional geodynamic events. This inference is consistent with the idea of the functional dependence of many biocoenotic shifts upon changing sedimentation settings (Zhizhhcenko 1969; Zubakov 1990).

Stabilising tectonic settings in the region of the Great Caucasus at the beginning of the Aptian, have led to rapid decrease in ferromagnetic input to the Cis-Caucasian Basin and, consequently, to sharp magnetisation decrease in bottom sediments. Starting from the Aptian, the Southern Land was no longer important as a sourceland. Thus, during the last stage of the Aptian-Albian sedimentation, the Northern Land, structurally linked to the margin of the Scythian Plate, becomes the principal distributive province.

The Aptian sequence is practically not differentiated according to scalar magnetic characteristics, which, under certain assumptions, may be interpreted as indicative of relatively stable tectonic settings. Judging from insignificant magnetism variations in the Albian sections, some activation has probably taken place in the end of the Early Cretaceous (Appendixes 5, 6, Fig. 4).

The regional redox potential reduction of deposition environment, constitutes a distinctive feature of the Aptian-Albian sedimentation within the North Caucasus. Anormally high concentrations of disseminated pyrite, reliably recorded from sharp k_t increases, are observed in all the sections studied, and testify to periodical contaminations of the bottom sediments in the Cis-Caucasia with hydrogen sulfide in the end of the Aptian (*P. melchioris* zone and the upper substage) and the Albian.

The magnitudes and durations of these process manifestations varied within wide ranges. Various intensities of dk in distant sections of the same ages (Fig. 4) are indicative of the changes in redox settings to have been peculiar in each of the facies zone (Fig. 4). In the Mineral Water District, the hydrogen-sulphide environment existed till the middle of the *P. melchioris* time. Within the Osetin syncline (the Urukh River) and Dagestan, it persisted till the end of the Albian.

The coincidences of thermokappametric and biostratigraphic units, registered in the Aptian-Albian beds from Dagestan (Appendixes 5, 6), seem quite logical. The changes in the redox potential of the deposition environment, as well as the hydrogen-sulphide contamination, are known to be controlled by palaeoclimate features and eustatic oscillations. The same factors influence biota evolution and the relationship between planktonic and benthic organisms in the palaeobasin. Thus, vertical distributions of the dk's, document the changes of faunal sequences within the sections considered.

As shown in Figure 4, the values of k and dk demonstrate obvious reverse relationships: the highly magnetic Hauterivian-Barremian parts of the sections are characterised by minimal increases of magnetic susceptibility, while, on the contrary, the highest dk values are recorded in the low magnetic Aptian-Albian sequences. The negative correlations between the k and dk diagrams are accounted for by the oxidising environment in the palaeobasin during the periods of tectonic activations, and by the favourable conditions for reducing settings in the deep parts of the reservoir during the periods of tectonic stabilisation.

CONCLUSION

The set of geologic and petromagnetic data provides the grounds for subdividing the Lower

Cretaceous Stage in the development of the North Caucasian Region into three steps, reflecting peculiar geodynamic and geochemical settings in various intervals of geologic time.

The first one, the Berriasian-Valanginian step, is peculiar for mainly carbonate deposition. The insignificant amount of detritus in the Berriasian deposits, and its almost complete absence from the Valanginian sequences, are indicative of quiet palaeotectonic settings and low erosion bases both, in the Southern, and the Northern lands.

The second, the Hauterivian-Barremian step, was characterised by intensive terrigenous drift against the background of general tectonic activation. The central part of the Great Caucasus becomes then one of the principal sourcelands, with fairly commonly developed granite and basite bodies – the main suppliers of magnetic materials to the region of marine accumulation. The Hauterivian-Barremian tectonic activation of the Great Caucasus might be a regional reflection of the final stage of the Late Kimmerian tectogenesis phase (Kunin & Sardonnikov 1976).

The third one, the Aptian-Albian step, coincides with tectonic stabilisation of the region associated with further northward transgression development. The Great Caucasus then has probably lost its importance as a supplier of terrigenous material, and the marginal regions of the Scythian Plate have once more become the principal distributive provinces. During that stage, the deposition was taking place in reducing hydrogen-sulphide settings. A correspondence can't be ruled out between the noted peculiarity of the Lower Cretaceous palaeogeochemistry in the basin, and the global anoxic events at the Early/Late Cretaceous boundary (Dale *et al.* 1992).

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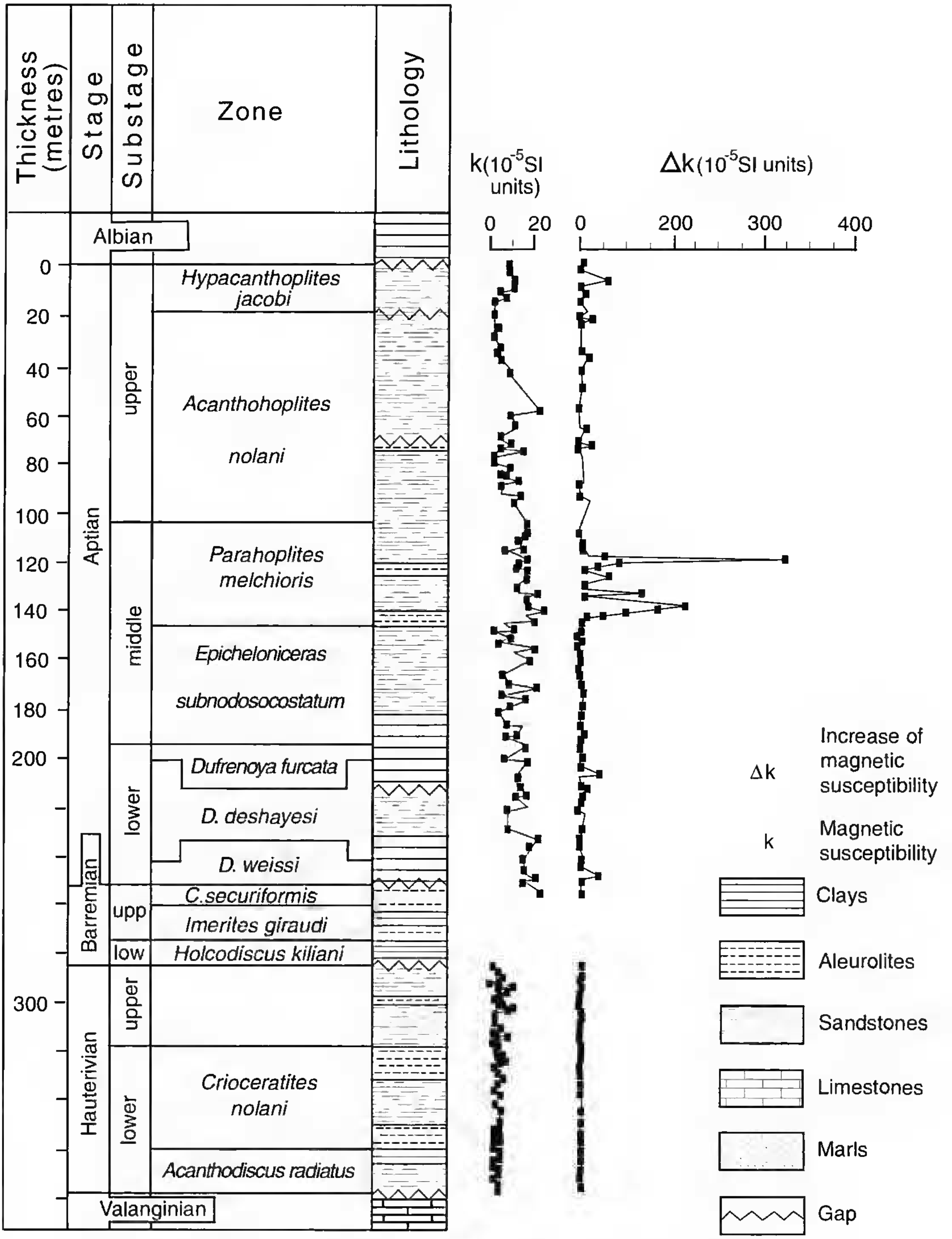
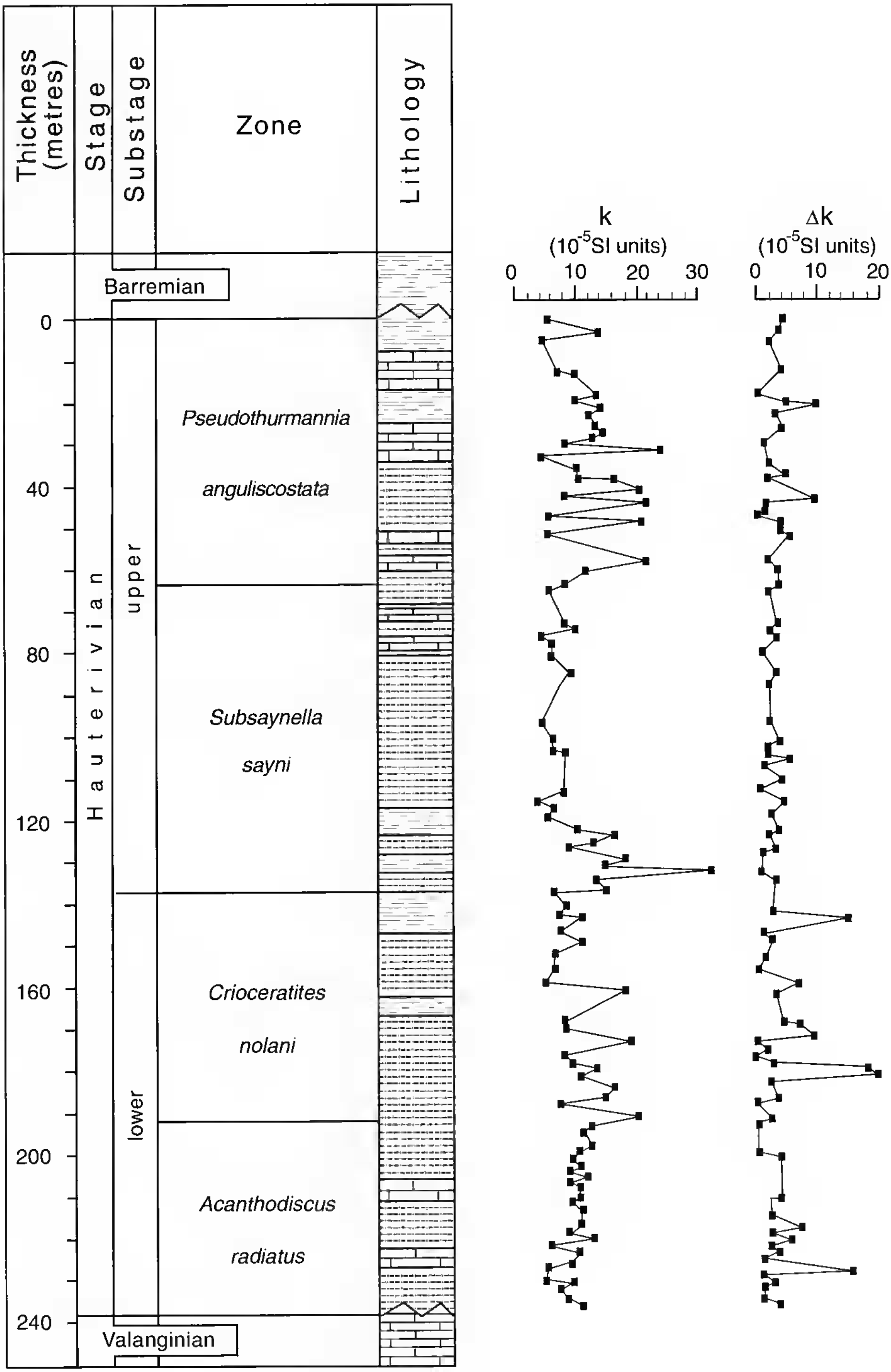
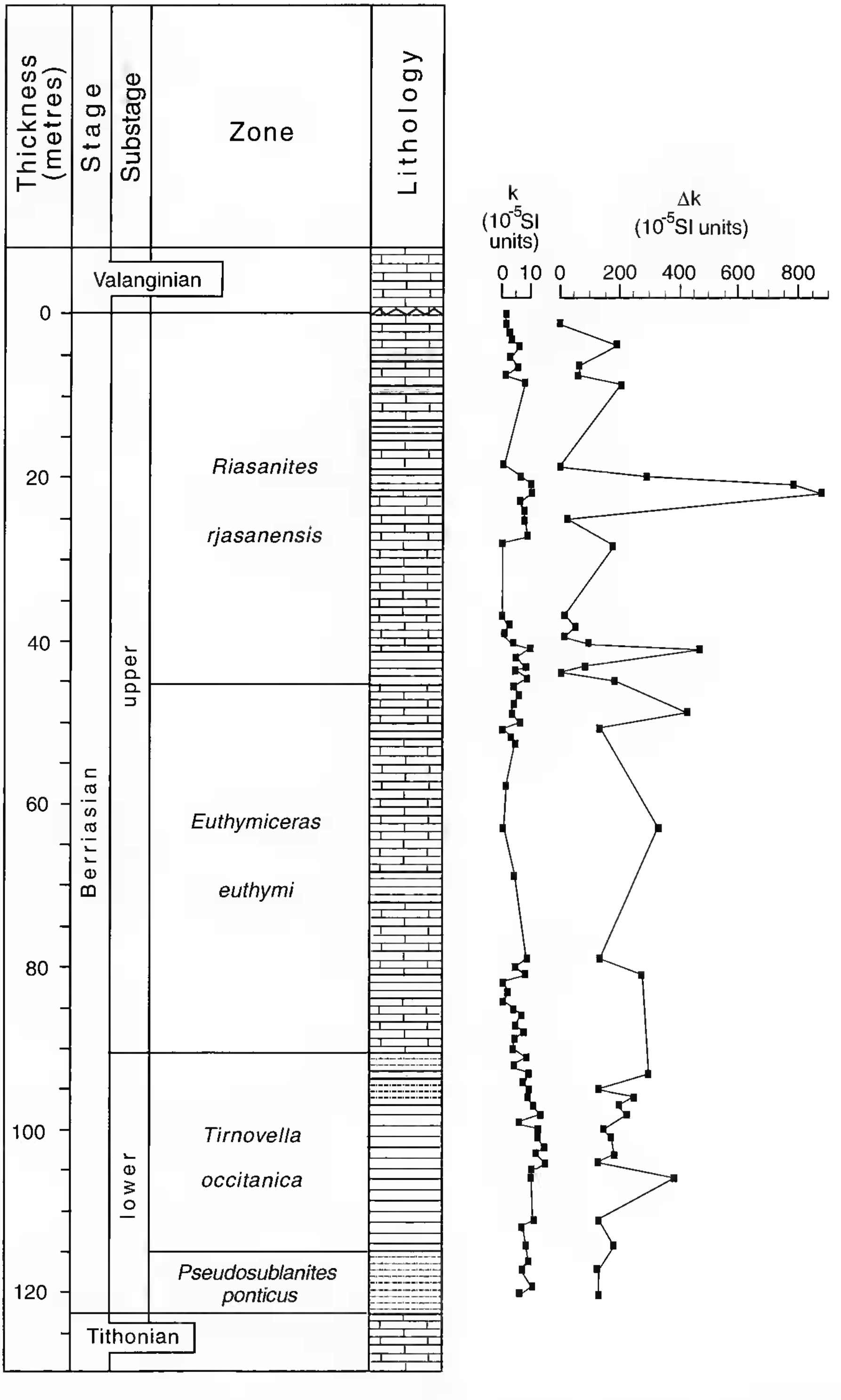
APPENDIX



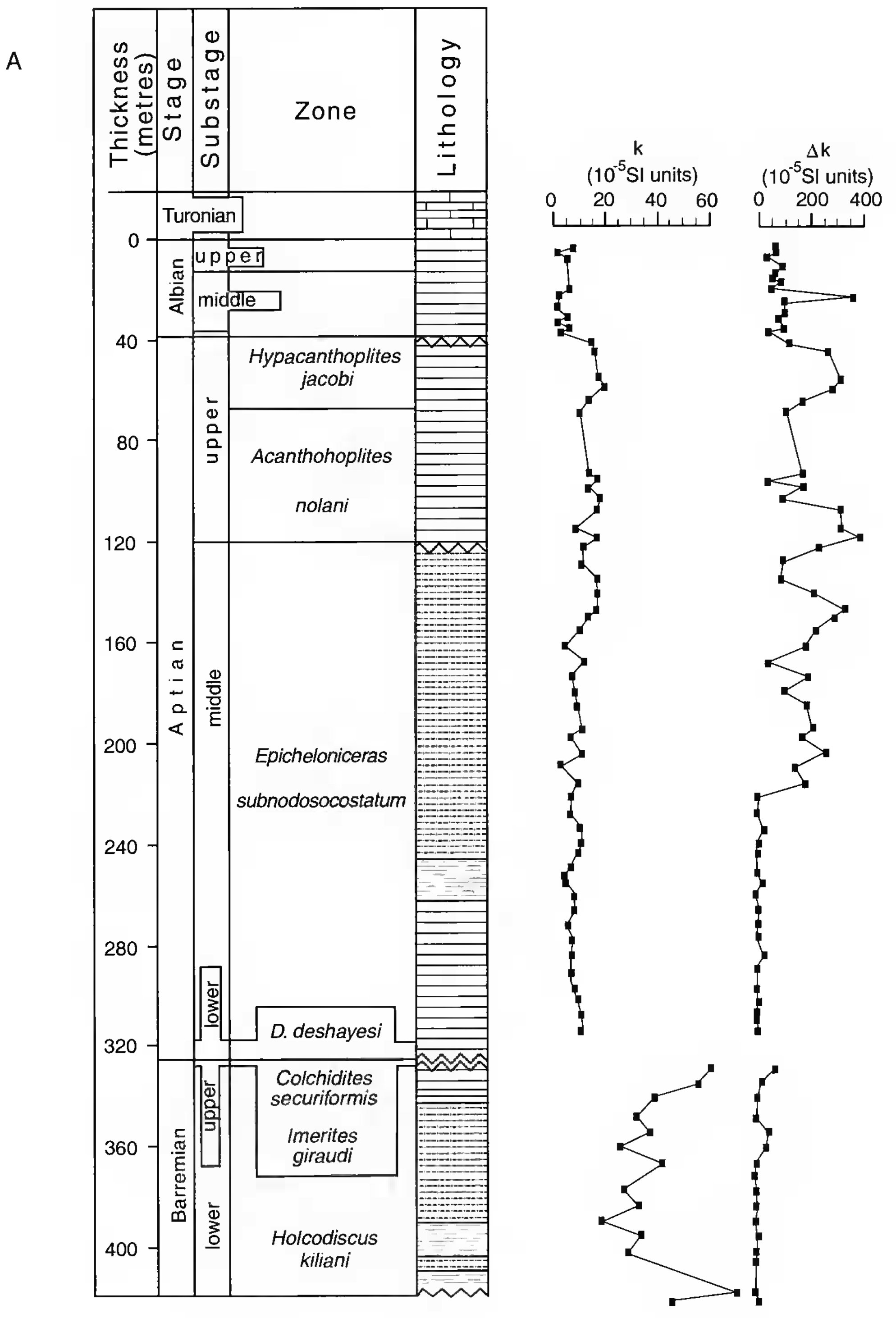
APPENDIX 1. — Petromagnetic characteristics of the Hauterivian-Aptian deposits from Kislovodsk Section.



APPENDIX 2. — Petromagnetic characteristics of the Hauterivian deposits from Baksan Section. For legend of lithology and gap, see Appendix 1.



APPENDIX 3. — Petromagnetic characteristics of the Berriasian deposits from Assa Section. For legend of lithology and gap, see Appendix 1.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(10-5SI units)
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Turonian
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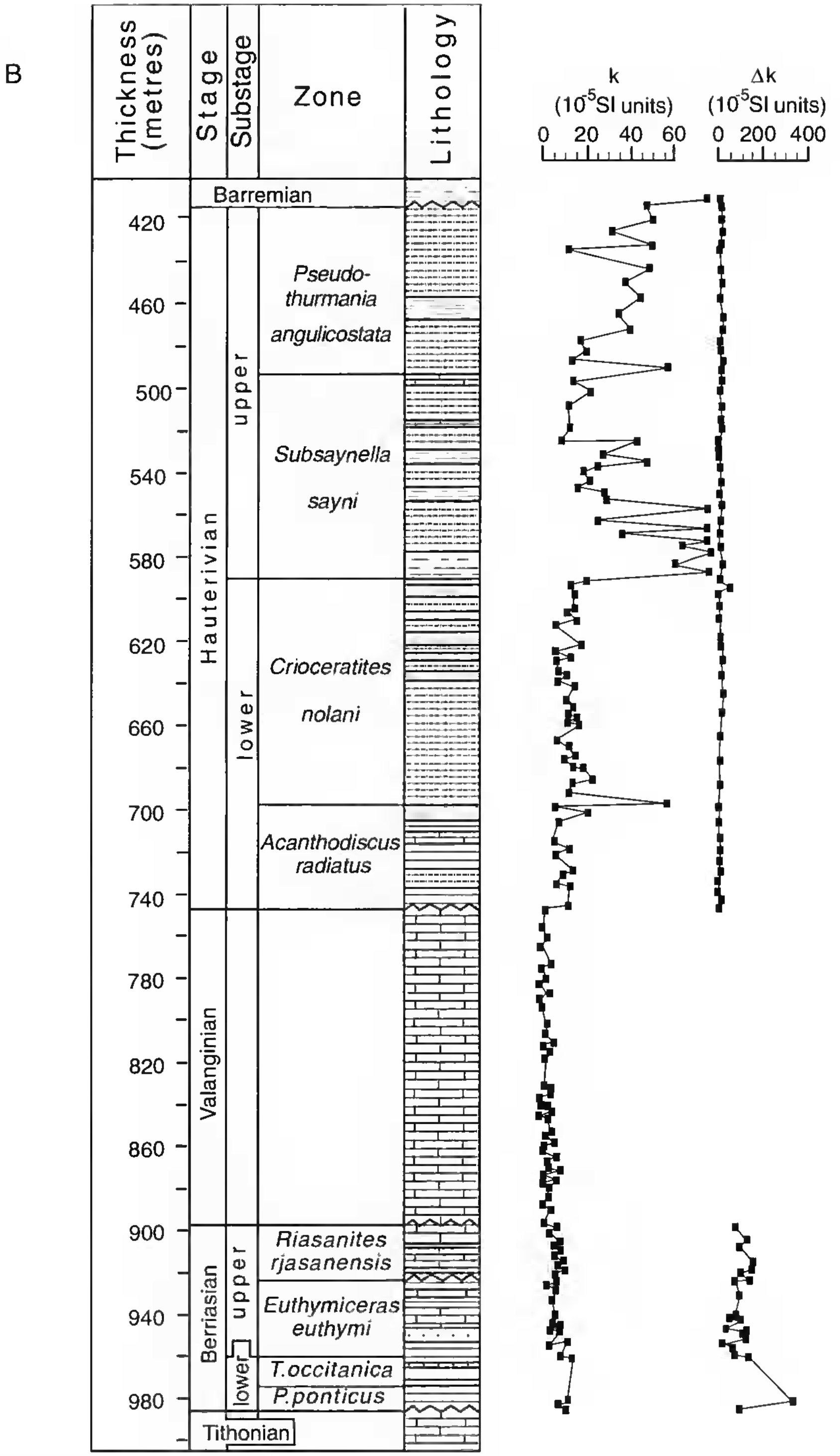
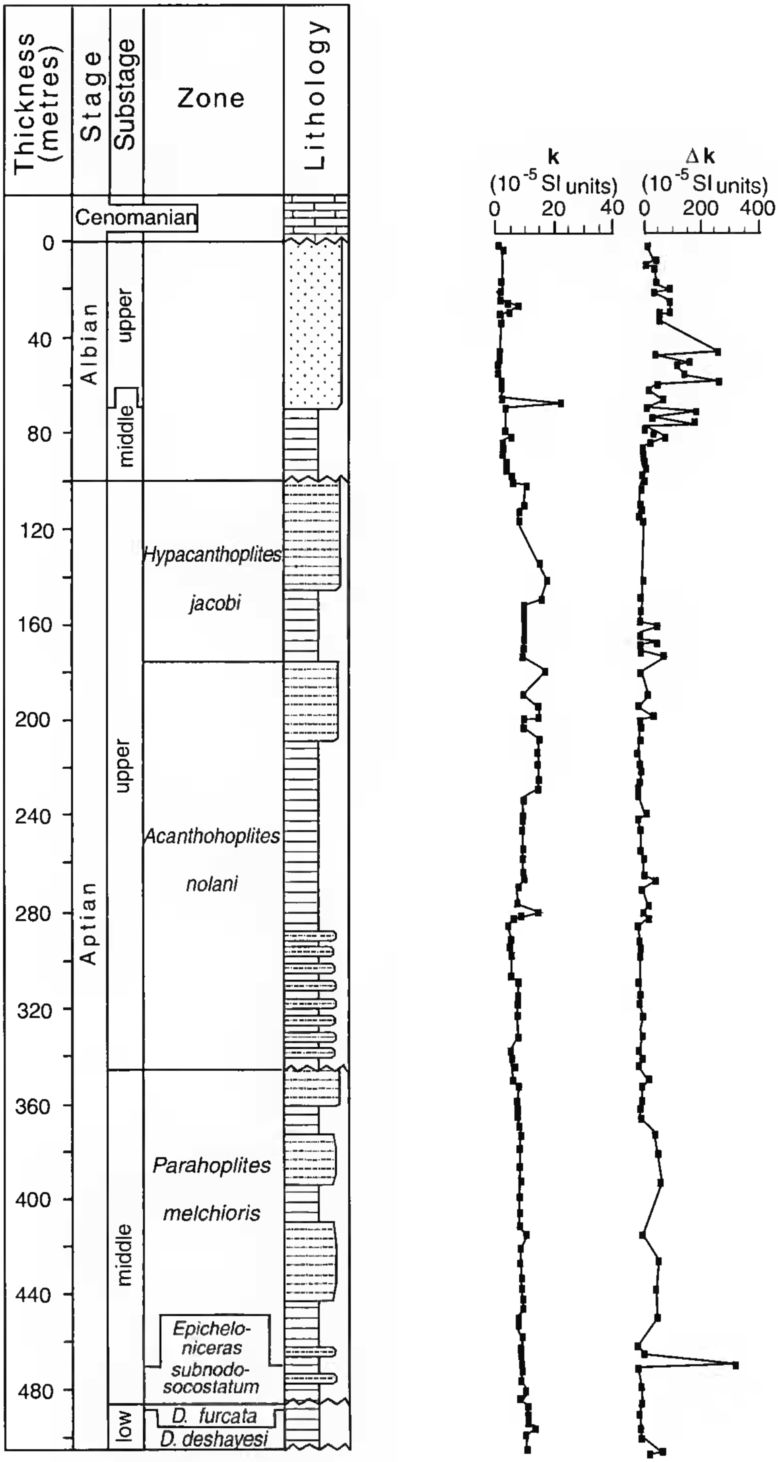
Albian
upper
middle
40
Hypacanthoplites jacobi
upper
80
Acanthohoplites
nolani
120
160
Aptian
middle
200
Epicheloniceras
subnodosocostatum
240
280
lower
D. deshayesi
320
Colchidites securiformis
upper
Imerites giraudi
360
Barremian
lower
Holcodiscus kiliani
400

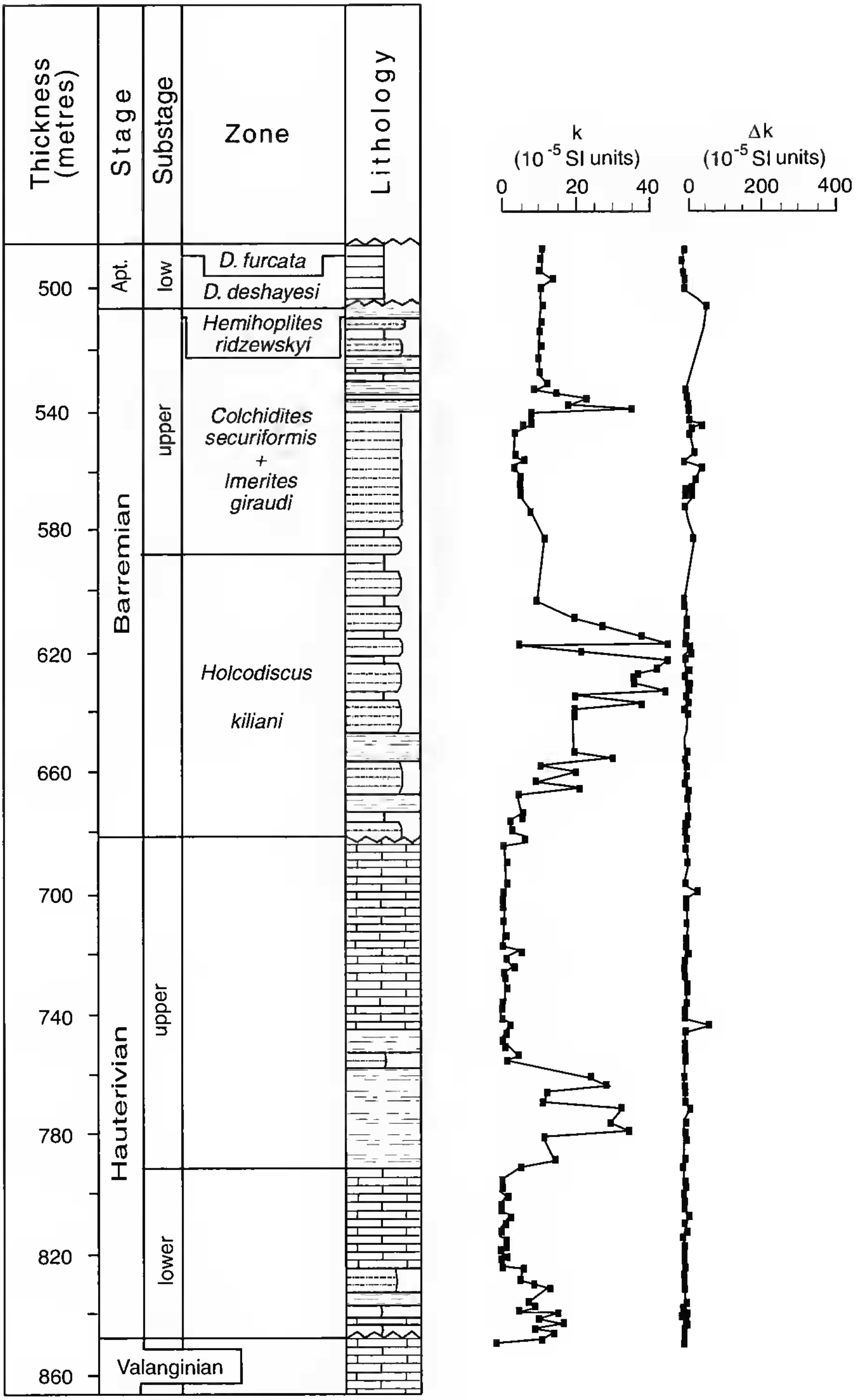


APPENDIX 4. — **A**, **B**, petromagnetic characteristics of the Berriasian-Albian deposits from Urukh Section. For legend of lithology and gap, see Appendix 1.

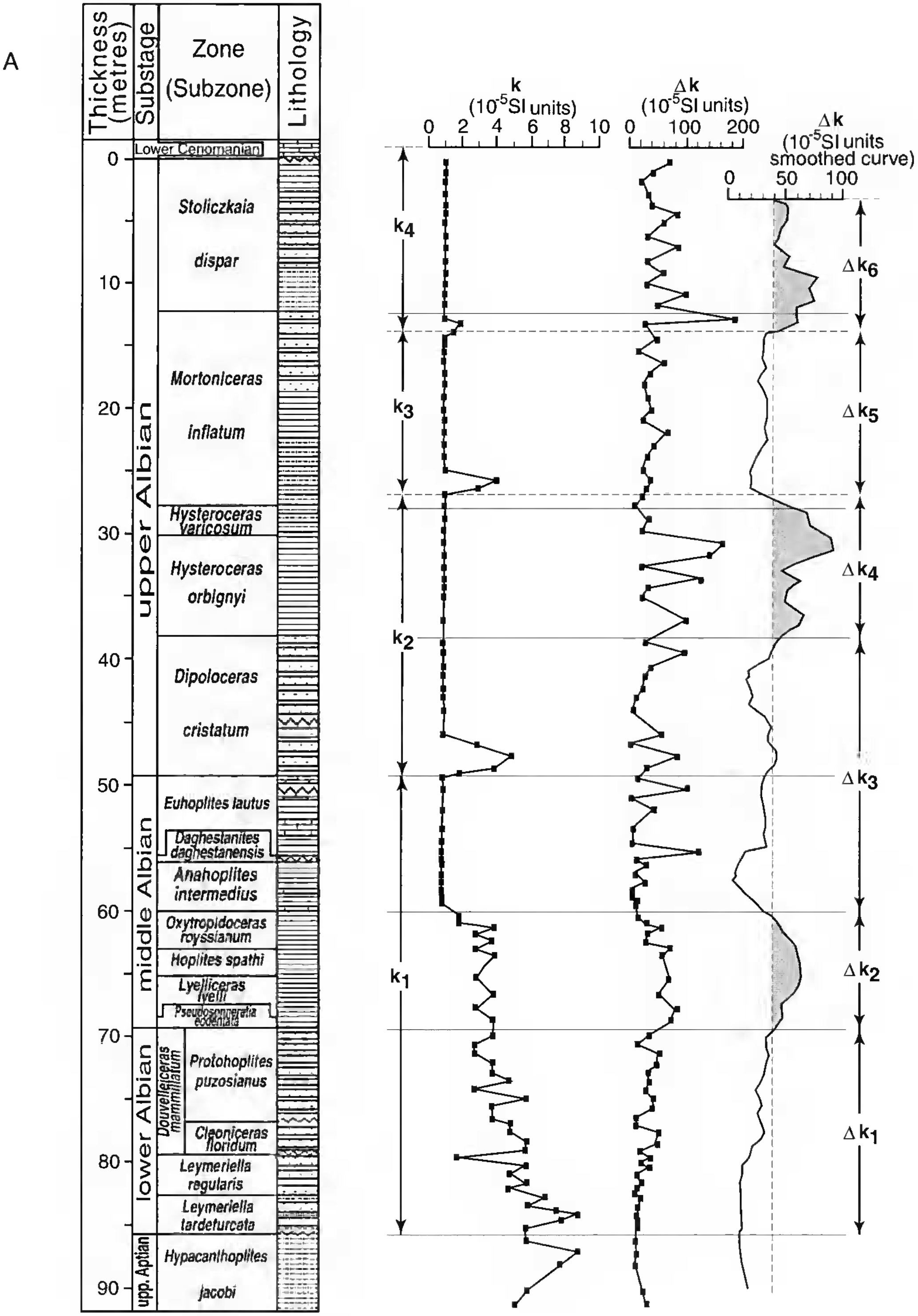
A

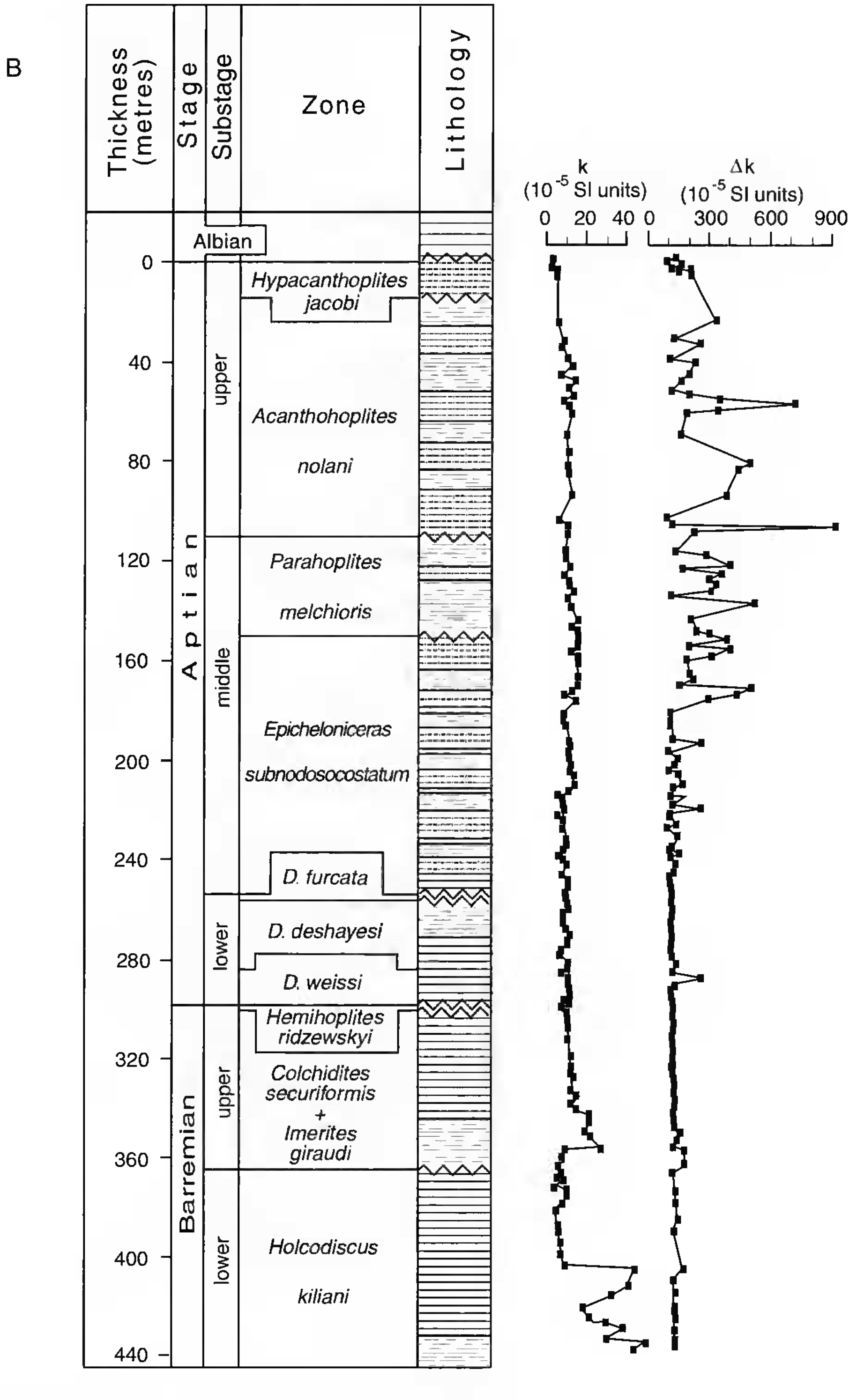

Thickness (metres)
Stage
Substage
Zone
Lithology
k
(10-5 SI units)
0 20 40
Δk
(10-5 SI units)
0 200 400
Cenomanian
Albian
upper
middle
Aptian
upper
middle
low
Hypacanthoplites jacobi
Acanthohoplites nolani
Parahoplites melchioris
Epicheloniceras subnodosocostatum
D. furcata
D. deshayesi
0
40
80
120
160
200
240
280
320
360
400
440
480

B



APPENDIX 5. — **A**, **B**, petromagnetic characteristics of the Hauterivian-Albian deposits from Gergebil Section. For legend of lithology and gap, see Appendix 1.


A
Thickness (metres)
Substage
Zone (Subzone)
Lithology
Lower Cenomanian
upper Albian
middle Albian
lower Albian
upp. Aptian
Stoliczkaia dispar
Mortoniceras inflatum
Hysteroceras varicosum
Hysteroceras orbignyi
Dipoloceras cristatum
Euhoplites lautus
Daghestanites daghestanensis
Anahoplites intermedius
Oxytropidoceras roissyanum
Hoplites spathi
Lyelliceras lyelli
Pseudosonneratia eodentata
Douvilleiceras mammillatum
Protohoplites puzosianus
Cleoniceras floridum
Leymeriella regularis
Leymeriella tardefurcata
Hypacanthoplites jacobi
k (10-5SI units)
Δk (10-5SI units)
Δk (10-5SI units smoothed curve)
k4
k3
k2
k1
Δk6
Δk5
Δk4
Δk3
Δk2
Δk1



APPENDIX 6. — **A**, **B**, petromagnetic characteristics of the Barremian-Albian deposits from Akusha Section. For legend of lithology and gap, see Appendix 1.